PART 5

LM FOOD CHAIN

Chapter 8. Model Application

The fish bioaccumulation models provide a dynamic linkage between polychlorinated biphenyl (PCB) levels in fish tissue and PCB concentrations in their exposure environment. They are valuable tools for helping us to obtain a quantitative understanding of the bioaccumulation and trophic transfer of PCBs in the lake. The bioaccumulation models can be applied to estimate PCB levels in the fish given the input of exposure concentrations in the water and surface sediment. Besides this common application, the models can also be used to derive estimates of PCB concentrations in the exposure environment based on observed fish PCB data. For example, fish bioaccumulation models have been applied, in conjunction with fate and transport models, to reconstruct the time history of contaminant concentrations in the environment (Gobas *et al*., 1995; DePinto *et al*., 2003).

In this chapter, the focus of model application is primarily on simulating future PCB levels in lake trout on the basis of projected exposure concentrations in sediment and overlying water that were provided by the LM2-Toxic model (see Part 4).

5.8.1 Simulation of Fish PCB Levels Based on Hypothetical Exposure Inputs

The food chain bioaccumulation model was developed as a component of an integrated series of the Lake Michigan Mass Balance models. One of the main objectives of the models was to evaluate the impact of PCB load reduction strategies on PCB concentrations in the Lake Michigan ecosystem. Several PCB load reduction scenarios were selected for model analyses. The PCB concentrations in water and sediment associated with each of the load reduction scenarios were estimated by the LM2-Toxic model (Part 4, Chapter 6). These predicted future environmental concentrations provided a basis for estimating corresponding fish PCB levels using the fish bioaccumulation models.

5.8.1.1 Exposure Concentration Inputs Used for Model Simulations

Environmental concentrations are the most critical input when models are applied to deduce the resulting PCB levels in fish. It cannot be over-emphasized that it is exposure input data which "drive" the models because, to a first approximation, fish PCB levels are proportional to the concentrations in its exposure environment.

Site-specific PCB concentrations in water and sediment were provided by the LM2-Toxic model for the Saugatuck and Sturgeon Bay biota zones. Regional average PCB environmental concentrations were also provided for two large areas denoted as segment 2 and segment 3 in the LM2-Toxic model, respectively. Segment 2 is the southeastern part of Lake Michigan surrounding the Saugatuck biota zone, and segment 3 is the northwestern part of the lake surrounding the Sturgeon Bay biota zone (see Figure 4.3.1).

For each site, a total of seven hypothetical scenarios of long-term (1994-2055) PCB environmental concentrations were provided as exposure input to the food chain models. These were generated by the LM2-Toxic model as a quantitative prediction of environmental concentrations under various PCB load reduction scenarios for the Lake Michigan ecosystem. As described in Part 4 (Chapter 6) of this document, the seven PCB load reduction scenarios were:

A) Constant Conditions – The measured PCB loads (tributary load plus atmospheric dry and wet deposition) for the LMMBP period (1994-1995), but adjusted upward by a factor of 1.98. The adjusted loads followed the same spatial distribution and monthly variation patterns established by the LMMBP measured PCB loads. The adjusted loadings, the 1994-1995 vapor-phase concentration, Lake Huron boundary conditions, and all other forcing functions as observed in 1994 and 1995 were repeated throughout the simulation period. Sediment burial was active as well as all other model processes.

B) Continued Recovery (Fast) – This was the same as Scenario "A", but atmospheric components (vapor phase concentration, wet and dry deposition) declined with a six-year half-life (Hillery *et al.*, 1997; Schneider *et al.*, 2001), and tributary loads declined with a 13-year half-life (Endicott, 2005; Marti and Armstrong, 1990). The boundary conditions at the Straits of Mackinac declined at a rate of 0.17/year (a four-year half-life) (Schneider *et al.*, 2001). These rates were applied starting on January 1, 1996.

C) Continued Recovery (Slow) – This was the same as Scenario "A", but atmospheric components (vapor phase concentration, wet and dry deposition) declined with a 20-year half-life (Buehler *et al.*, 2002) and tributary loads declined with a 13-year half-life. The boundary conditions at the Straits of Mackinac declined with a four-year half-life. These rates applied starting on January 1, 1996.

D) No Atmospheric Deposition – This was the same as Scenario "A", but starting on January 1, 1996, the atmospheric loads (dry and wet deposition) were set to zero. All other forcing functions as observed in the LMMBP period were repeated throughout the simulation period.

E) No Tributary Loadings – This was the same as Scenario "A", but starting on January 1, 1996, all tributary loads were set to zero. All other forcing functions as observed in the LMMBP period were repeated throughout the simulation period.

F) Lakewide Sediment Cleanup – This was the same as Scenario "A", but starting on January 1, 1996, the lake-wide sediment PCB concentration was instantaneously set to zero. All other sediment properties remained as existed prior to sediment clean-up. All other forcing functions as observed in the LMMBP period and processes were repeated throughout the simulation period.

G) No Atmospheric Deposition and No Tributary Loadings – The loading cuts of Scenarios "D" and "E" were combined. All other forcing functions as observed in the LMMBP period were repeated throughout the simulation period.

Each of the seven long-term PCB concentration scenarios consisted of a set of congener-specific PCB concentrations in the water column and surface sediment as functions of time. As an example, some congener-specific PCB exposure concentration data for Sturgeon Bay corresponding to Scenario A (continuation of current PCB loading) are presented in Figures 5.8.1a and 5.8.1b) as provided by the water quality model (LM2-Toxic).

5.8.1.2 Responses of Fish Models to Different Exposure Inputs

The food web models calibrated for Saugatuck and Sturgeon Bay lake trout food webs were used for the modeling exercise in this chapter. The Saugatuck model was applied to simulate fish bioaccumulation in response to exposure concentrations for Saugatuck and segment 2. The Sturgeon Bay model was applied to simulate fish bioaccumulations in response to exposure concentrations for Sturgeon Bay and segment 3. We believe that these bioaccumulation models can reasonably represent PCB concentrations in fish as a function of exposure concentrations in water and sediment for the calibrated biota zones. For the large segments (two and three) beyond the sites for which the models were calibrated, the reliability of the models becomes uncertain.

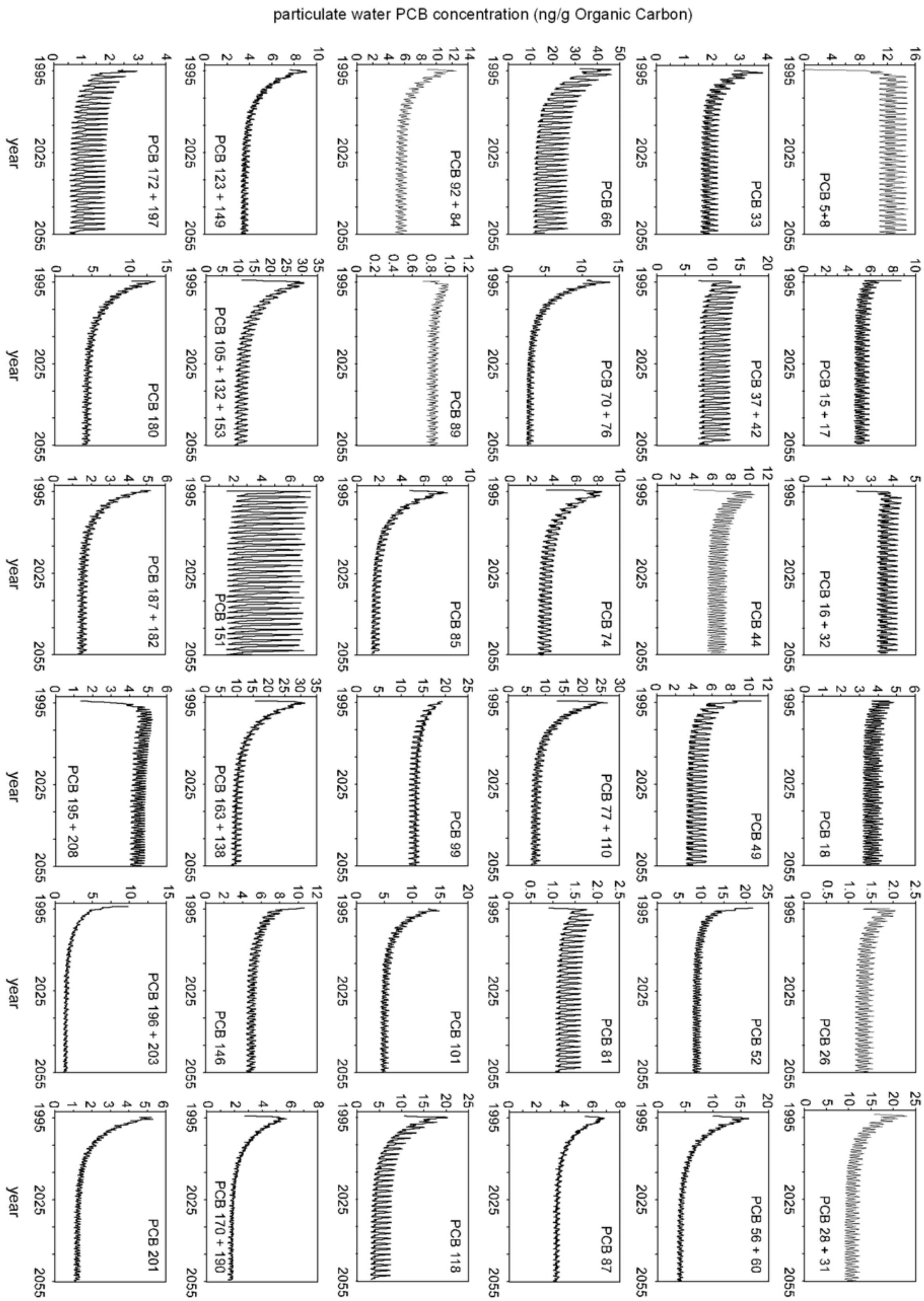

Figure 5.8.1a. PCB congener-specific exposure concentrations at Sturgeon Bay predicted by LM2-Toxic for Scenario A – PCBs in suspended particles of the water column.

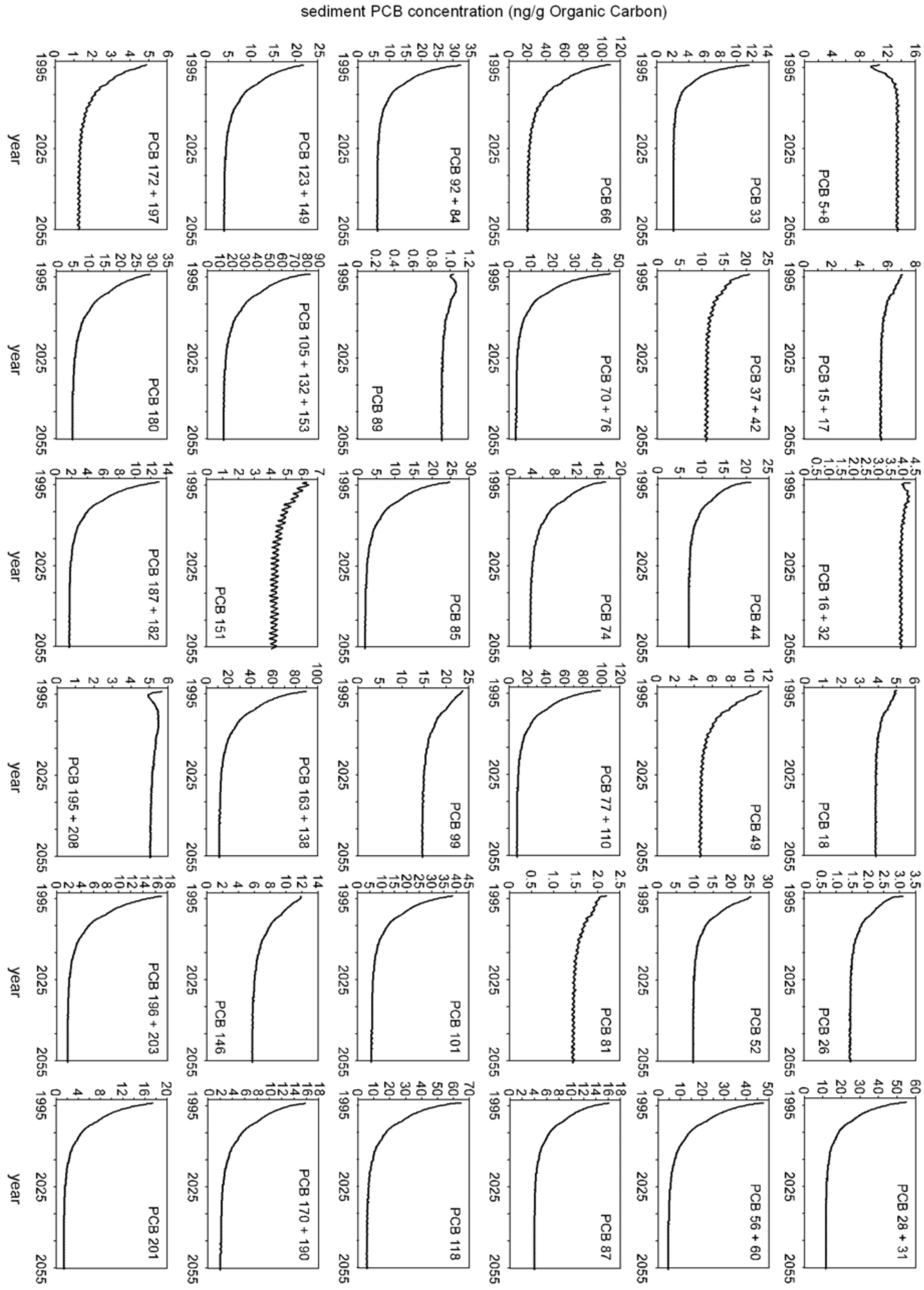

Figure 5.8.1b. PCB congener-specific exposure concentrations at Sturgeon Bay predicted by LM2-Toxic for Scenario A – PCBs in the surface sediment.

The extrapolative applications of the calibrated models to segments 2 and 3 were carried out on assumptions that the average environmental concentrations in large segments were good representations of the exposure conditions for fish in the segments, and that the food web structures used in the models were still representative beyond the specific biota zones.

However, caution should be taken while interpreting these model outputs because assumptions may or may not be valid. For example, there is evidence that lake trout are usually congregated in nearshore areas (Rybicki and Keller, 1978; Schmalz *et al.*, 2002). This implies that lake trout caught in any area of Lake Michigan may have actually spent a large portion of their living history in nearshore areas and were exposed to PCB concentrations found there. Therefore, interpretation of the segment-specific fish model results need to take the actual home range of fish into consideration.

A fundamental assumption of the fish model application is that the food web structure, related biological parameters (such as growth and consumption rates for each species) and environmental elements (such as annual temperature) will remain the same over the entire time period of the model simulations. Aside from this assumption, the reliability of the fish model estimates is primarily dependent on the quality of model inputs for PCB concentrations in water and sediment (see Part 4, Chapter 6).

Fish model simulations were initiated with the assumption that PCBs in fish at day zero of the model simulations (January 1, 1994) were at steady-state with the exposure concentration. The temporal trend of PCB concentrations in lake trout food web species were estimated in response to different hypothetical long-term exposure concentrations at Saugatuck and Sturgeon Bay, segment 2 and segment 3. The simulation results in terms of total PCBs in an adult lake trout (age 5.5) are presented in Figures 5.8.2 and 5.8.3.

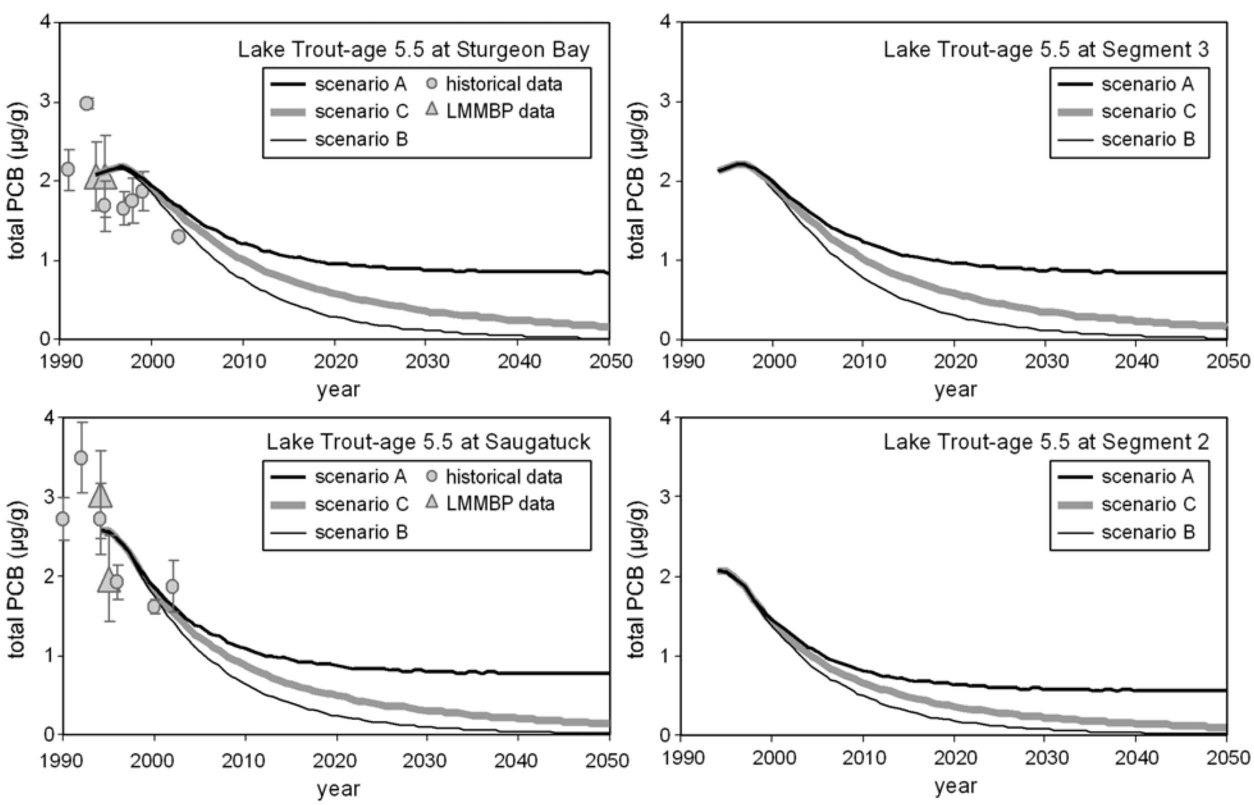

Figure 5.8.2. Total PCB concentrations of the lake trout in response to the exposure concentration inputs associated with various loading scenarios.

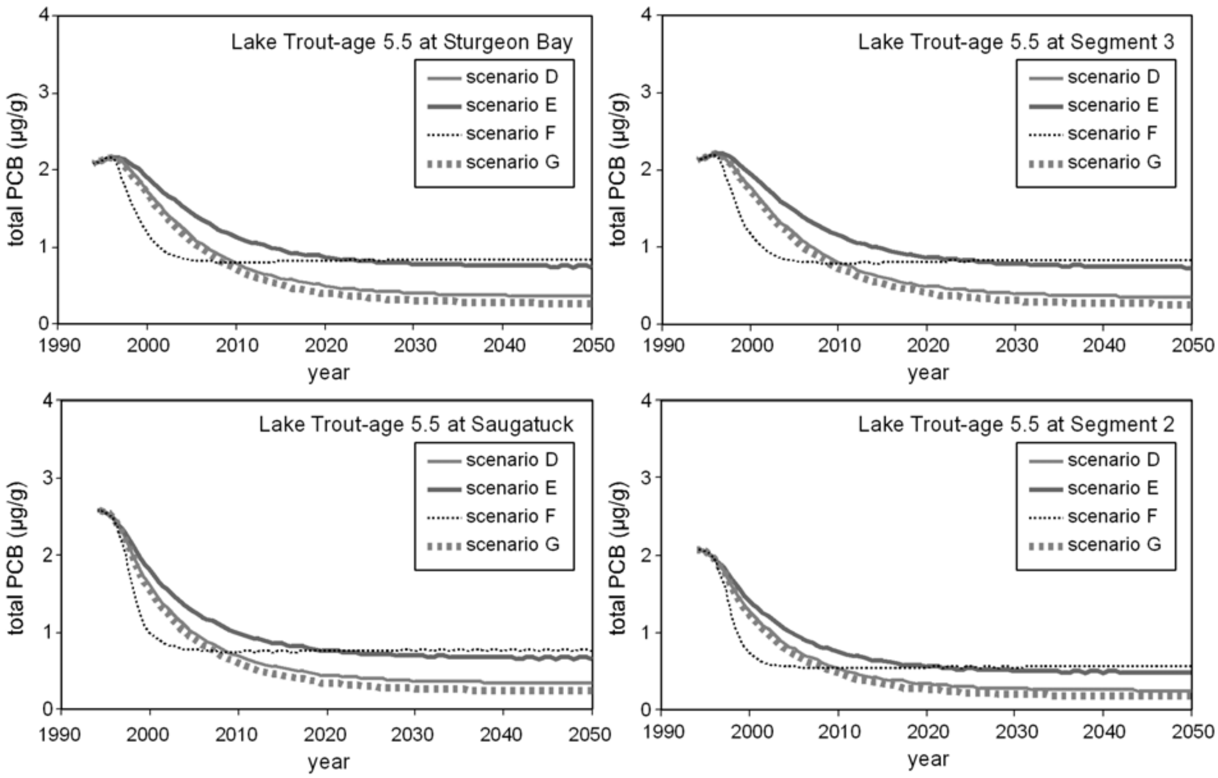

Figure 5.8.3. Total PCB concentrations of the lake trout in response to the exposure concentration inputs associated with various loading scenarios.

The model estimates of total PCB values were calculated based on the sum of fish model results for individual PCB congeners. The age 5.5 lake trout represents the average of five and six year-old lake trout and was selected for illustration because of the availability of long-term observed PCB data for the lake trout at similar ages. The observed total PCB data were also included in the figures for the Saugatuck and Sturgeon Bay biota zones.

The results show that the fish model simulations made for Sturgeon Bay and segment 3 have very similar outputs. This is because environmental exposure concentrations for these two sites were almost identical, and the model for these two sites used the same food web.

The results also show that the fish model outputs for Saugatuck and segment 2 were different. Because the model simulations for these two sites used the same food web structure, the difference can be attributed to the different exposure concentrations used for their simulations.

The results further indicate that, under the same loading scenario, projected PCB levels in lake trout declined at a much faster rate at Saugatuck and segment 2 than at Sturgeon Bay and segment 3. The difference in rates of decline in fish PCB concentration was a result of similar declining trends in the PCB exposure concentrations used as input for fish model simulations.

Assuming exposure inputs from the LM2-Toxic model are reasonable depictions of future environmental PCB concentrations in Lake Michigan under different PCB load reduction scenarios, the fish models predicted that total PCB concentrations in age 5.5 lake trout will level off in response to constant external loading in 2040 (Scenario A) at all four sites. The estimated steady-state values of total PCB concentrations in lake trout are expected to be 0.84 μg/g-wet for Sturgeon Bay and segment 3, and 0.77

µg/g-wet and 0.56 µg/g-wet for Saugatuck and segment 2, respectively. The higher final value estimated for segment 3 (0.84 µg/g-wet) in comparison to segment 2 (0.56 µg/g-wet) is consistent with observations (LMMBP data) that the lake trout food web at Sturgeon Bay has a substantially higher bioaccumulation capacity than the one at Saugatuck.

Based on the exposure input data provided by the LM2-Toxic model, the fish models further suggested that for the fast recovery scenario (Scenario B), the targeted total PCB concentration for fish (0.075 ppm, see Appendix 3.4.1) would be achieved in about 2036 at Sturgeon Bay and segment 3, and 2033 and 2030 at Saugatuck and segment 2, respectively. All other PCB reduction scenarios do not achieve the targeted PCB levels in the lake trout within the time period of the model simulations (2055).

5.8.1.3 Discussion

It should be noted that the temporal trend of total PCBs in lake trout for each load scenario (Figures 5.8.2 and 5.8.3) was the result of combined contributions from the fish model results for individual PCB congeners. For each of the PCB congeners, the concentration temporal trend in the fish was largely a reflection of the time functions of the exposure concentrations for water and sediment, as shown in Figures 5.8.1a and 5.8.1b.

The temporal trends of total PCB concentrations in water and sediment for various PCB load scenarios were illustrated in Part 4 of this report (Figures 4.6.3 and 4.6.5). These lake-wide average data are a good representation of the site-specific environmental total PCB concentrations used for the food web bioaccumulation model simulations.

As expected, the model results illustrate that future PCB levels in fish are closely related to the projected environmental concentrations. For example, the total PCB concentrations in age 5.5 lake trout associated with the Scenario B (Fast Continued Recovery) are the lowest of all scenarios at the end of the model simulation (Figure 5.8.2). This result is similar to that for the modeled total PCB concentrations in water and sediment (Figures 4.6.3 and 4.6.5). Similarly, the dramatic decline at the early stage of the model simulation in fish PCB levels associated with the Scenario F (Sediment Cleanup) (Figure 5.8.3) is the result of the parallel trends in the total PCB concentrations for water and sediment (Figures 4.6.3 and 4.6.5). Among the PCB load reduction scenarios, the sediment cleanup scenario appears to have the most immediate impact on PCB concentrations in water and sediment and consequently on PCB levels in the fish.

For the total PCB concentrations in the fish at the Sturgeon Bay and Saugatuck biota zones, the model generated temporal trends for all scenarios appears to be in line with the expected trend inferred from the field data. Comparing Scenarios B and C, the Continued Recovery (Fast) (Scenario B) appears to fit the field data better at both locations. Additional field data are needed to confirm this observation.

It should be emphasized that the model results are the product of the model, its structure, and the assumptions made. Because the results of fish bioaccumulation models are highly dependent on exposure concentrations, the model results should be interpreted in light of uncertainty in the exposure predictions (Part 4, Chapter 6).

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